TOWARDS RESILIENT LOW-MIDDLE INCOME APARTMENTS IN AMMAN, JORDAN: A THERMAL PERFORMANCE INVESTIGATION OF HEATING LOAD

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Abstract
Energy security constitutes a major challenge for Jordan's sustainable development. Space heating in Jordan represents ~61% of total residential energy consumption and dominantly involves portable un-flued kerosene and LPG stoves. Fuel combustion of such heaters generates poor indoor air quality and emits GHGs. Moreover, recent housing condition surveys show that the majority of dwellings in Jordan are very energy inefficient. This paper assesses the thermal performance of existing urban low-middle income apartments in Amman. This aim was approached through surveying 106 sample units and using EnergyPlus engine to calculate thermal performance of two representative apartments. Findings showed that ~75% of the apartments had thermally poor external envelopes. Analysis revealed that ~64% of heat loss can be attributed to exposed walls and roofs. The present research found that 'thrift retrofitting' will be inevitable in any effort in Jordan to deliver resilient low-middle income apartments.

Keywords Apartment, Heat Loss, Retrofit, Resilient.

1.0 Introduction
The Policy Framework for Developing Countries 2012, published by the United Nations Human Settlement Programme (UN–Habitat), has highlighted energy efficiency and indoor quality as common principles to be considered with regards to environmental footprint and resilient houses. The framework identifies a sustainable house as one that has been designed, erected and managed to be healthy; that is supplied by secure and affordable energy resources; and that qualifies as resilient against possible climatic influences and natural catastrophes (1).

However, energy security stands out as a major challenge to sustainable development in Jordan (2). The energy problem in the country has been described as "chronic" due to the lack of natural resources capable of supplying energy and the resulting dependence on import for most energy needs, which leaves the energy sector very vulnerable to international energy prices (3). The fuel prices in Jordan, for example, continue to escalate, and their volatility has negatively affected the low-income class of the society (4). Generally, low-middle income apartments in Amman/Jordan have been most affected by the energy crisis in Jordan (5).

As in most developing countries, Jordan is heavily reliant on importing energy and a large number of dwellings in the country are characterized by significant energy losses, which contribute to higher levels of CO_2 emissions (6). Building stock constructed in the last decades in Jordan is claimed to be "not well adapted to the climate", which means that more energy is consumed for cooling and heating purposes (7).

The dominant thermal load of residential stock in the country is heating, which consumes ~61% of the stock's total energy (8,9) and ~14% of total annual demand on national energy (9) for heating spaces.

The majority of households in Jordan still heat their houses using un-flued kerosene and LPG heaters in addition to fixed flued stoves (9). These traditional methods produce indoor pollutants and emit CO_2 to the atmosphere, leading eventually to serious health and environmental hazards (10).

This paper assesses the thermal performance of existing urban low-middle income apartments in Amman, the capital of Jordan, with the aim of investigating their resilience status and associated potentials. This work sheds light on many of the thermal, health, economic and environmental issues related to low-middle income housing practices in Jordan. To the best knowledge of the authors, in the context of Jordan, especially in the capital Amman, few studies have investigated whole apartments' thermal performance through analysing construction elements. The methodological approach undertaken in this paper is thus unique.

2.0 Jordan: A developing country

2.1 Overview

Classified as an "upper-middle income country" (11), Jordan is situated on the Northern side of the Arabian Peninsula and has an area of 89,318 km^2 (12). The country is highly urbanized (2); based on statistics from 2013 in the document "Jordan in Figures (2013)", ~83% of the population lives in urban areas. The same document also reported that ~39% of the total estimated population lives in Amman (13), which is the "economic and industrial hub" of the country (14). According to Younis et al. (5), Jordanian society can be categorized into four groups: below poverty, below-middle income, middle income and affluent classes. The first two classes form the low-income group. The same authors also found in their research that low- and middle-income households, which together constitute ~74% of all the urban households in Amman, seem to be vulnerable to the ramifications of the energy crisis in Jordan. Fuel poverty, for example, often leads to thermal discomfort inside these houses.

2.2 Climate in Jordan

Jordan can be divided into three physiographic zones: the desert (East), the highlands (Centre) and the agricultural Rift Valley (West). The capital, Amman, is located within the mountainous and hilly highlands, where altitudes vary between 600 m and 1600 m (7). The cooling season is dominant in the desert and Rift Valley zones, whilst the heating season is dominant in the highlands. The average temperatures in the capital are 8.1°C in January and 25.1°C in July. Johansson et al. (7) based the aforementioned winter and summer climatic zoning in their research on Heating Degree Days (HDD) and Cooling Degree Days (CDD) calculations, respectively, and the two zones then were verified using thermal computer simulation. According to Tahboub (15), the winter months in Jordan are from November to April and can be "very cold", snowy, windy and rainy, especially in Amman.

These distinct climate zones in Jordan advocate for different strategies and approaches for energy efficient buildings (7). According to Shariah et al. (16), as 'regional-dependant' variables, meteorological conditions are a factor that effectively influences heating and cooling loads and energy saving approaches in a building. For example, the influence of regional climates on the creation of energy efficient buildings may have led Mauro et al. (17) to further consider summer overheating when retrofitting residential stock in cooling dominated climates. The same researchers claimed that the retrofitting of existing residential buildings to achieve a zero energy target is possible, but only in heating dominated climates. However, the researchers referred to some techniques to avoid overheating in summer in warm climates, such as applying solar overhangs, using reflective coatings or even passively cooling indoor spaces (17). These discussions on summer overheating would inform the recommendations that will result from the present paper.

2.3 Energy in Jordan

Jordan's lack of local energy resources generates many challenges in the energy sector in Jordan (18). Primarily, Jordan mainly relies on importing energy (2,18), which is needed in huge amounts to achieve social and economic development. According to a World Bank document published in 2015, energy imports in Jordan in 2014 constituted 27.2% of total imports of goods compared to 18% of 2009 levels. Such growth in imports of energy, as reported by the same document, makes Jordan increasingly vulnerable to international fuel supply shocks (19). Relatively, Karaki et al. (20) have reported that Jordan spends about 10.9% of its GDP to import energy, yet less than 2% of the total energy mix in Jordan involves application of renewable energy techniques (20). Hence, the challenges and vulnerability in energy security have led the government to recognize the necessity of adopting fundamental structural reforms towards enhancing the operational and financial performance of the energy sector in Jordan (19).

Moreover, Al-Ghandoor et al. (6) have concluded that demands on fuels and electricity are predicted to surge by 23% and 100% respectively by 2018. According to the same authors, this jump would consequently imply a 59% increase in GHGs emitted by residential stock by the same year, and that increase would compound the urgency of employing robust energy conservation measures. The need for applying such measures were also highlighted by Beithou et al. (21) and Al-Azhari and Al-Najjar (22) in light of the projected increase of energy consumption figures for the residential sector in Jordan.

Furthermore, Alkurdi et al. (3) called for further study of the accessibility to and the quality of energy supplied to households in Jordan, as these factors are directly correlated to fuel poverty. The same researchers highlighted two reasons for studying the residential stock in Jordan in relation to the problem of energy, fuel poverty and end user interests: first, the functional importance of the house operating twenty-four hours per the day to secure the optimum comfort level: second, residential buildings constitute the largest sector of building stock in Jordan (3). The following section briefly discusses residential buildings in Jordan.

2.4 Residential Stock in Jordan

According to a Government report, ~32,000 housing units are demanded annually in Jordan; that number is driven by the need for erecting new units as well as for upgrading already existing stock (4). Significant licensed construction areas of 1, 2.14 and 1.78 million m^2 in the periods of 2000, 2007 and 2008 respectively have mainly belonged to domestic buildings, with the majority of the recent constructions in Jordan located in Amman (7).

The “Jordan Poverty Reduction Strategy” report revealed that the apartments in the country form 73% of the total housing stock and more than 80% of all buildings across all cities in the kingdom (2). Yet only 5% of this stock is wall insulated and none is roof insulated (10), allowing significant energy losses to cripple the energy efficiency of the houses (6). In their report issued in 2009, Johansson et al. (7) claimed that buildings erected in the last decades in Jordan are “not well adapted to the climate”, which would imply the need for more cooling and heating loads (7).

In their research on low-middle income apartments in Amman/Jordan, Younis et al. (5) statistically analysed the tabulated data of the “Household Expenditures and Income Survey” for the years 2006, 2008 and 2010, which were “bespoke” data provided for the researchers by the Department of Statistics/Jordan. The researchers found from the data in 2010 that the dominant construction materials for the external envelope of low-middle income apartments in urban Amman are concrete hollow bricks and plaster; the envelopes of these apartments thus have a thermally poor performance (5). According to El Hanandeh (23), this type of wall configuration has a U-value of 2.38 $W/m^2.K$. This is a high figure considering the recommended value in the range of 0.50–0.70 $W/m^2.K$ recommended by Johansson et al. (7,24) and Ouahrani (7,24) as the optimum range for the wall and roof configurations of apartments in Amman/Jordan. This parameter, as claimed by Ouahrani (24), significantly influences heating and cooling demands and eventually affects users’ thermal comfort.

The following section thus investigates the health implications of the heating devices used by households in Jordan.

2.5 Heating Devices Used and Their Health Implications

Houses in Jordan mainly rely on combustion of fossil fuels to heat spaces and water for domestic use (9,10). Younis et al. (5), in their analytical study referred to above, found that kerosene/diesel and LPG heaters were the dominant stoves utilised by low-middle income households in urban Amman. Younis et al. (25) investigated the heating devices used by households through a survey of 106 low-middle income apartments in urban Amman/Jordan. The researchers reported that ~39% and ~89% of the total surveyed households have used un-flued kerosene and LPG stoves respectively to heat their spaces. In the same study the authors also found that ~65% of respondent households used more than one heating device to keep their apartments warm.

Combustion of fossil fuels is a major contributor to air pollution and CO_2 build-up in the atmosphere (9). Moreover, combustion of un-vented stoves utilised for heating spaces emits high levels of toxic by-products, such as CO, which might frequently exceed their approved levels and create a poor indoor environment (9,10). For instance, the resultant mixture of pollutants produced by combustion of kerosene is extremely carcinogenic and significantly affects the indoor quality of dwellings, particularly when the dwellings are poorly ventilated (26).

The government of Jordan is determined to reduce GHGs by 14% by 2030, a commitment revealed in its submission of Jordan’s Intended Nationally Determined Contribution (INDC) (27-29) to the United Nations Framework Convention on Climate Change (CoP21) in 2015 (27). Yet, the government requires the donors and the international community to support it in reducing the 12.5% by the same year, while the balance 1.5% reduction would be achieved using its own means (27,28). His Majesty King Abdullah II, at the Paris Climate Conference 2015 (CoP21), delivered a “pressing appeal” for action in which he highlighted the energy concerns in the country and the necessity of working together towards saving the entire planet (29). Jordan was the first Middle Eastern region to clearly demonstrate a commitment to addressing climate change; the action strategy (29,30) aims to boost energy supply to counter the insecurity growth in the country (30). This plan obviously stress the critical position of energy security in the country, as discussed in section 2.3 above, and the urgency of reducing GHGs emissions.

Jaber et al. (10) have indicated that in addition to the gaseous pollution of kerosene, LPG produces water vapour, which condenses on cold surfaces creating optimum environments for damp and fungi inside houses, especially poorly ventilated ones. According to the Scientific Committee on Health and Environmental Risks (SCHER) (31), exposure of indoor environments to mould growth and dampness is recognized as a “microbes” factor that affects well-being and health, eventually resulting in asthma and allergic airway disease ramifications.

In an experimental study conducted by Johansson et al. (7) in a typical apartment in Amman, the ventilation rate in winter was as low as 0.31 ach. The low ventilation rate is partly due to a preference to keep windows closed as people try to keep warm. Eventually, the poor ventilation generates significant health hazards. Unhealthy environments develop as a result of dampness and mould growth and carbon dioxide and monoxide emissions.

The above literature indicates that low-middle income apartments in urban Amman are energy inefficient. Also, the aforementioned discussions under sections 2.4 and 2.5 have highlighted the poor fabric configuration of the apartments that has in turn triggered the usage of dual nature heating stoves to raise households’ thermal comfort. Hence, it could be claimed that households compromise on keeping warm to cope with the ever-escalating fuel prices in the country, leading to fuel poverty concerns. Low-middle income households may prefer to keep the un-flued traditional heating stoves rather than attempt to upgrade them to sustainable and healthy heating devices based on renewable energy sources. Eventually, however, this preference would worsen the already existing negative contributions of residential stock to the surrounding environments due to the GHG emissions.

Hence this paper aims to investigate the thermal performance of the apartments in question and to assess their resilience potentials. The following chapter discusses the methodology used to approach this aim.

3.0 Research Methodology

3.1 Methodological Approaches

Assessment of the thermal performance of existing urban low-middle income apartments in Jordan's capital of Amman has been conducted through a dual approach. First a field survey was conducted in winter 2015 of the five urban sub-districts of Amman. The survey employed a sample of 106 low-middle income apartments. Distribution of the sample was informed by data provided by the Department of Statistics/Jordan (DoS) for the distribution of households over the five urban sub-districts—Qasabat Amman, Marka, Al-Jama'a, Al-Queisma and Wadi Al-Seir—over three periods of time. The DoS has supplied the researchers with bespoke data including the "Household Expenditures and Income Surveys" 2006, 2008 and 2010 (32-34). Percentage distributions of households across urban Amman over the five sub-districts were calculated accordingly to yield representative samples of the apartments in question. Semi-structured interviews were conducted with respondents to gain information related to respondents' apartments and thermal comfort. The respondents were able to inform the researcher about the construction configuration of the external envelopes of their houses.

Secondly, two of the surveyed low-middle income apartments were statistically selected to match most properties and represent two prototypes of the total 106 houses. Also, the two householders were found the best helpful in providing the required data for the researchers whenever were acquired. This methodology informed the second part of the paper's approach, which involved simulating the prototype models in question using the thermal dynamic simulator EnergyPlus 8.1. A range of simulations were run to calculate steady-state zone sensible heating for the living room in each modelled apartment, as the interviews indicated that the living room was the most heated room among the surveyed households. These simulations informed the investigation and hence the validity of the results.

3.2 The Apartment Prototype Specifications

Both of the selected prototype model apartments were semi-detached, as shown in Figure 1 and Figure 2 below, and located on the third floor (the top floor) within their buildings as illustrated in Figure 3 below. The top floor is the most critical location for an apartment within a building, as apartments on the top floor have their ceilings exposed to the outdoor environment. Several researchers have taken a top floor apartment as the prototype model in their studies for dynamic simulation (7,35); Alshorafa (35) for example, considered the top floor in his study for its criticality. El Hanandeh (23), in his study on assessing construction configurations for a single family house in Jordan, illustrated a typical roof configuration that he claimed to be a typical one in Jordan. Based on this illustration and on Jaber's (10) claim on the lack of the roofs of residential stock in the country to the insulation (see section 2.4), Figure 4 below illustrates a schematic section for the top roof assumed in this paper for the two prototype apartments.

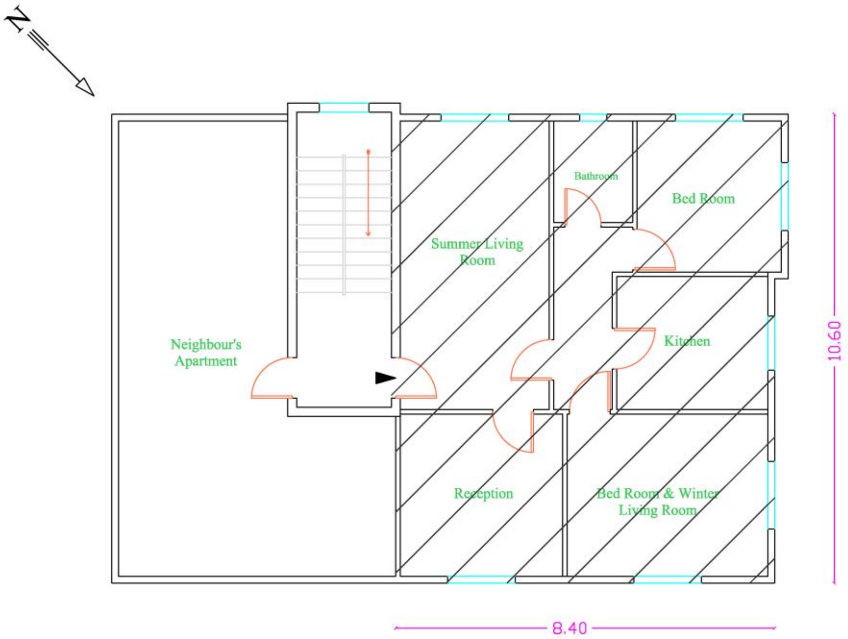

Figure 1 – Schematic plan of the semi-detached low-income apartment

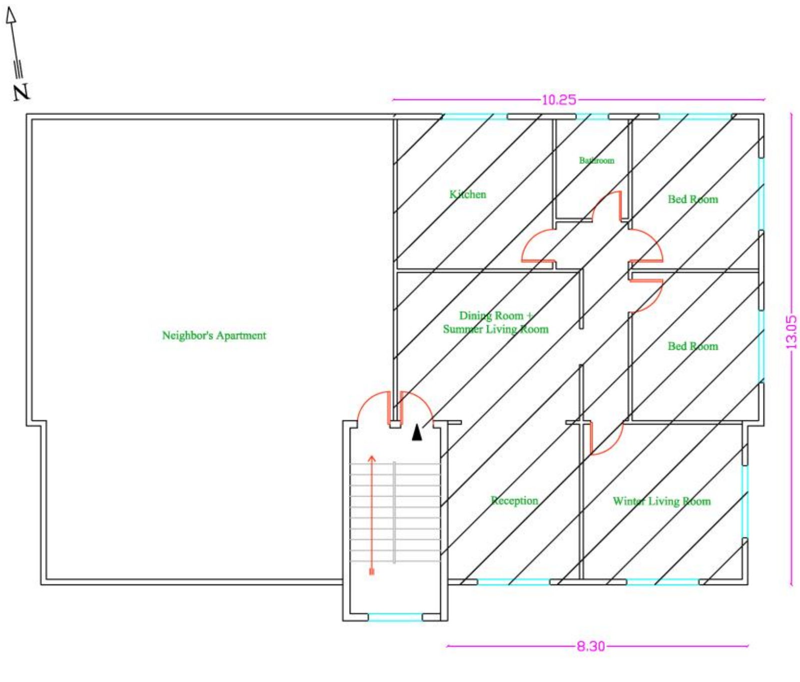

Figure 2 – Schematic plan of the semi-detached middle-income apartment

Figure 3 – Photographs of the low-income apartment (*left-surrounded*) and the middle-income apartment (*right-surrounded*)

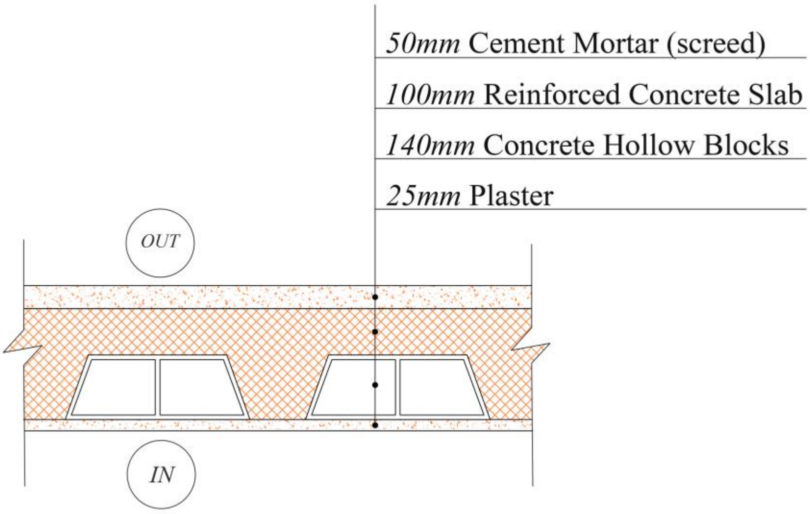

Figure 4 – Schematic section for the top roof configuration of the modelled prototype apartments.

The selected low-income apartment was critical as the average measured dry-bulb temperatures inside both the least heated room and the most heated room (winter living room) were found to be lower than the outdoor temperatures. Both selected apartments were the only two where it was possible to collect the required data, such as layout photographs, whenever needed, compared to other sample units.

The low-income apartment is around 81 m^2, was built in 2008 and has an average household size of 6. The middle-income apartment has an area of around 126 m^2, was erected in the 1980s and has an average household size of 7.

4.0 Results and Discussions

The semi-structured interviews conducted through the survey revealed that the external walls of the surveyed apartments could be classified into nine types of configurations. Analysis of the collected data indicates that the majority of the external walls were constituted, as illustrated in Figure 5 below, of two layers of cement plaster with a 15-cm sandwiched layer of concrete hollow blocks/bricks. This type of configuration will be referred to as type-A for presentation purposes in this paper.

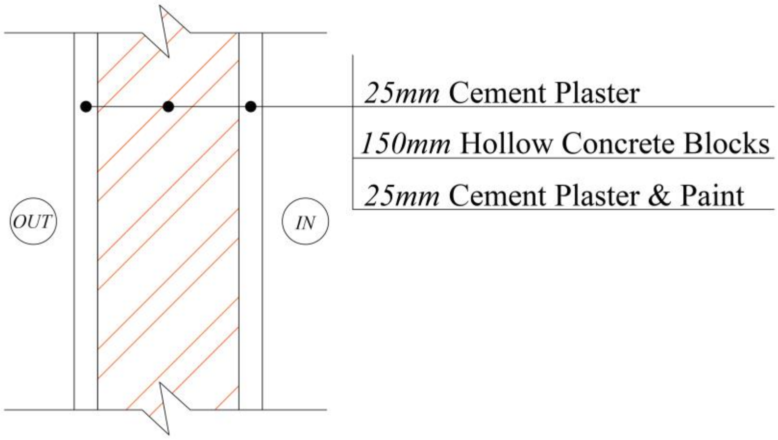

Figure 5 – Schematic cross section shows dominant external wall configuration found in surveyed apartments, Type-A (*not to scale*).

The analysis found that ~75% of the surveyed low-middle income apartments had type-A external wall configuration, including those apartments that had this type mixed with other construction types, but with type-A as the dominant type, as shown in Figure 6 below. The chart shows clearly that type-A was the dominant configuration in the external envelopes of both low- and middle-income apartments.

This finding was merely referred to in Younis et al.'s study (25); it will be elaborated on in this paper. This outcome coincides with the discussions in section 2.4 above, which highlighted the poor external skins of the housing sector in Jordan in general and particularly in Amman.

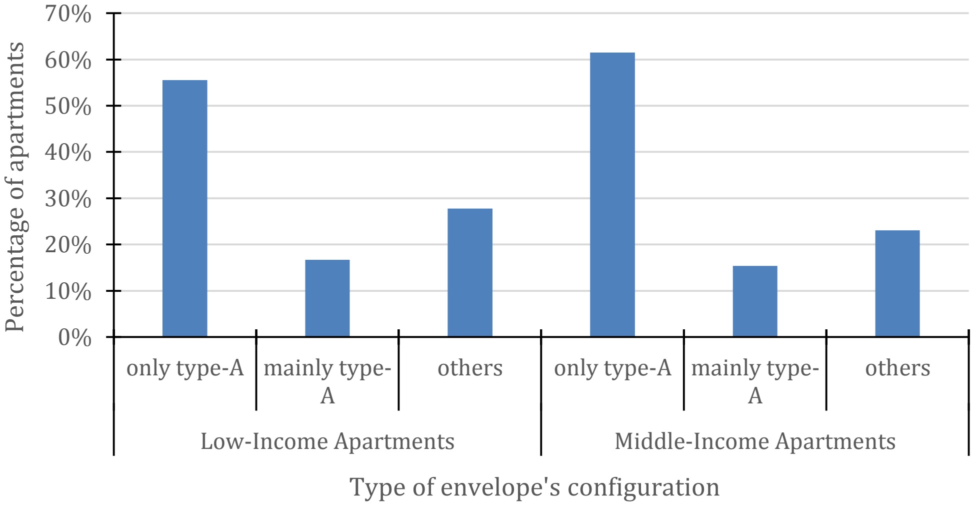

Figure 6 – Percentage distribution of surveyed low- and middle-income apartments by type of external envelopes' configuration.

These findings prompted further investigation into heat losses through such apartments. The investigation was carried out by running a range of simulations for two prototype models of low- and middle-income apartments, as explained above in section 3.0. The simulations have demonstrated steady-state sensible zone heating and a range of temperatures as well. Figure 7 and Figure 8 below detail the heat losses in the living rooms of each modelled apartment. The energy balance was calculated in the extreme scenario of the winter months, during which external dry-bulb and internal heating set-point temperatures were assumed as 1^{o}C and 20^{o}C, respectively.

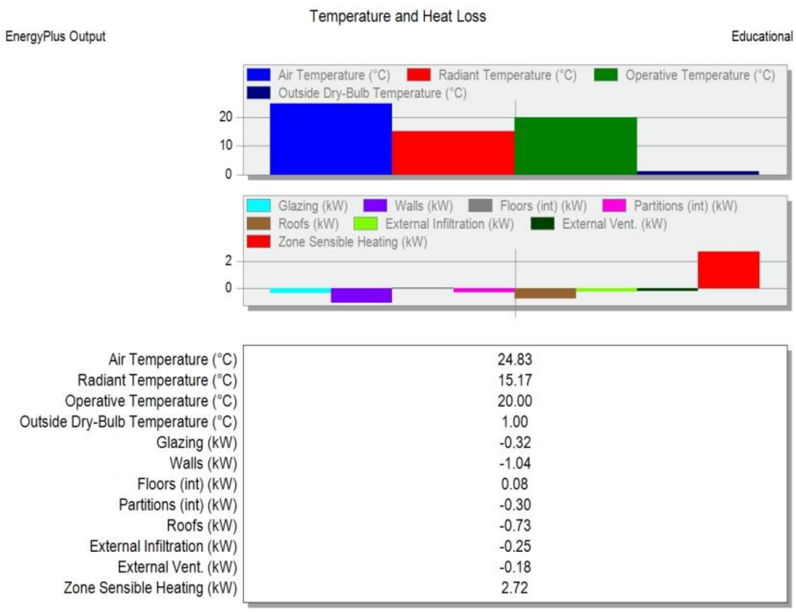

Figure 7 – Temperatures and heat losses for the living room of the prototype low-income apartment, produced by EnergyPlus.

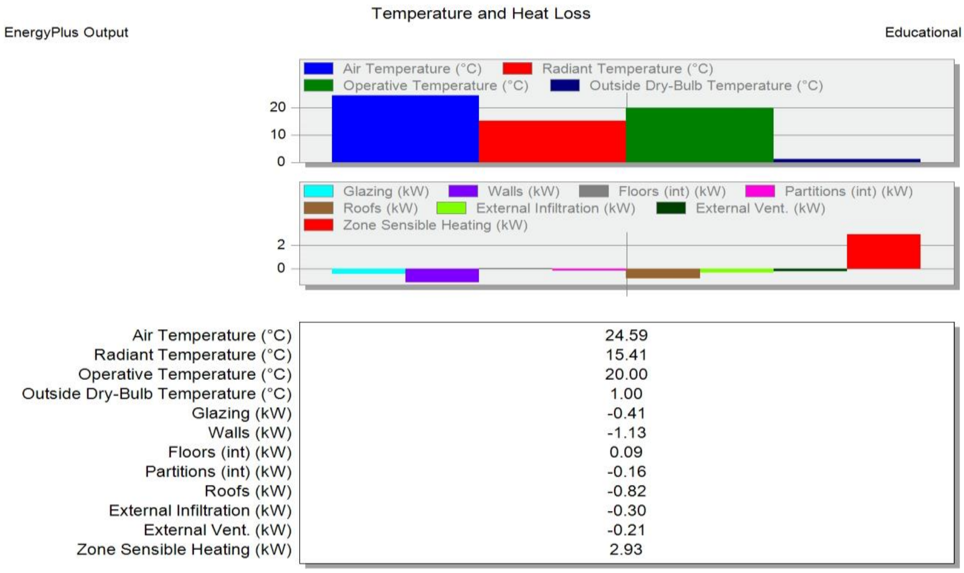

Figure 8 – Temperatures and heat losses for the living room of the prototype middle-income apartment, produced by EnergyPlus.

Comparatively, it could be inferred from Figure 9 below that most heat losses in both apartment models could be attributed to the roofs and the external walls, with only minor variation between the figures. Exposed fabrics have been identified as the most energy inefficient element in the apartments followed by the roofs, as the roofs contributed to the majority of heat losses in the modelled prototypes. Generally, dynamic thermal simulation of the modelled low- and middle-income apartments resulted in different amounts of heat losses through different elements of their living rooms, with ~64% and ~65% of these losses attributed to walls and roofs respectively.

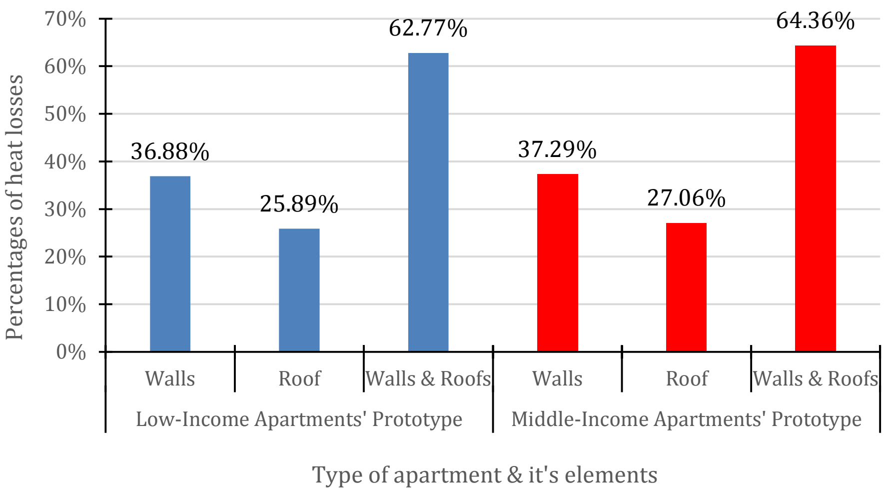

Figure 9 – Percentage distribution of heat losses out of total, by elements of low and middle income apartments' modelled prototypes.

As described above and in section 3.2, the results have been obtained for the mostly heated rooms in the building and hence show energy efficient indicators. Hourly interval simulations were run for a total of 3,479 hours of usual winter months in Jordan to calculate the thermal comfort inside the living rooms in question. The results showed that (~32% and ~53%) and (~32% and ~55%) of the total simulated hours for low-income and middle-income modelled rooms respectively had T_{op} values less than 18^{o}C and 20^{o}C, respectively. In their research on Jordan and specifically Amman, Johansson et al. (7) suggested using ASHRAE comfort standard-55 for studying comfort zones in Jordan. Accordingly, they determined that the comfortable T_{op} for Jordan in winter, at 50% relative humidity (RH), was in a range of 20–23^{o}C, with minimum thermal comfort temperature for Amman in winter at 18^{o}C. Furthermore, the World Health Organization (WHO) has recommended 21^{o}C and 18^{o}C as adequate warmth levels for the main living area and for other occupied rooms, respectively (36). Several researchers, such as Liddell et al. (37) and Howden-Chapman (38), have referred to these recommended temperatures particularly when discussing fuel poverty implications.

The findings of the present research on heat loss and the significant percentages of hours in which operative temperatures did not comply with comfort standards highly correlate with the finding above about the thermally poor configuration of the external fabric of the apartments in question. Accordingly, these outcomes reveal the thermal performance of such apartments to be energy inefficient. As the discussion in section 2.4 indicates, buildings generally and the residential sector specifically are energy inefficient, and a large stock of existing dwellings in Jordan are subject to significant energy losses. These failures in the construction eventually increase cooling and heating loads and hence CO_2 emissions.

5.0 Conclusions and Recommendations

This paper has assessed the thermal performance of existing low- and middle-income apartments in urban Amman by investigating their resilience and associated potentials. This investigation was facilitated by surveying a sample of 106 low-middle income apartments in winter 2015 and simulating two representative prototype apartments using the thermal dynamic simulation engine EnergyPlus 8.1.

The significant fabric heat losses that occurred in the living rooms of the simulated prototypes have been attributed largely to the thermally inefficient external skin of the apartments in question revealed in the field survey. This existing thermally poor fabric resulted in unhealthy internal environments that do not comply with the indoor air temperature standards for thermal comfort of ASHRAE and WHO. EnergyPlus has demonstrated that a high of ~53% and ~55% during the total simulated hours for usual winter months in Jordan in the same rooms of low- and middle-income apartments respectively had operative temperatures (T_{op}) less than 20^{o}C.

Based on the reviewed literature, the results of the field survey and the range of dynamic thermal simulations carried out for the prototype apartments, this paper calls for designing thrift retrofit packages for low-middle income apartments in urban Amman as an inevitable remedy. Low carbon retrofit interventions for these existing buildings would help the Jordan government to fulfil its commitment in terms of CO_2 reductions. Upgrading exposed walls and roofs followed by window configurations may need to be prioritized due to these elements' massive contribution to the heat losses of the apartment compared to other elements' contributions. Around 37% and 27% of total heat losses demonstrated by the simulation engine EnergyPlus for the living rooms of low- and middle-income apartments were attributed to external walls and roofs, respectively, constituting together ~64% of total heat lost by all related elements of the room in question in each apartment.

Using as many locally manufactured materials as possible could add value to the recommended sustainable solutions, as this approach would cut cost on transportation, reduce carbon emissions, secure new jobs and eventually provide the final product for the end users at a competitive price.

A retrofitting approach, according to the aforementioned discussions, particularly those in section 2.2, is likely to deliver resilient apartments for the households in question. Given the context of the study is Amman, where the heating load dominates, and in light of Mauro et al.'s (17) claim, in section 2.2 above, on summer overheating inside retrofitted houses, it could be claimed that retrofitting measures might positively impact on cooling demand. However, this paper recommends addressing this issue through further research.

Overall, these recommended proposals are believed to 'thriftily' deliver resilient apartments for vulnerable households. Retrofitting can upgrade these households' socio-economic status and alleviate their fuel poverty as well. Eventually, surrounding environments could also highly benefit from this approach, assuming it does, as anticipated, curtail GHG emissions.

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